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# WAFER PROBE

## BACKGROUND OF THE INVENTION

The present invention relates to a probe for testing of integrated circuits or other microelectronic devices.

One type of probe utilizes a spaced-apart array of slender needles to contact pads on a device under test (DUT). A signal is provided to the DUT, and the voltages and/or currents at the selected nodes are routed to measurement equipment. A problem encountered with such measurement systems, particularly at high frequencies, is that the close proximity between the needle tips creates inductance that can interfere with accurate measurements. Though this inductance can be reduced by limiting the isolated portion of the probe tips to the region immediately surrounding the DUT, practical considerations make such a design difficult.

Probe structures have been developed to compensate for the inductance at the probe tips. One such design is exemplified by Lockwood et al., U.S. Patent No. 4,697,143. Lockwood et al. disclose a ground-signal-ground arrangement of strip like conductive traces formed on the underside of an alumina substrate so as to create coplanar transmission lines. These coplanar transmission lines extend from the pads of the DUT at one end to a coaxial cable at the other end. The associated pair of ground traces on each coplanar transmission line is connected to the outer conductor of the coaxial cable and the interposed signal trace is connected to the inner conductor. Areas of wear-resistant conductive material are provided to reliably establish an electrical connection with the respective pads of the DUT. Layers of ferrite-containing microwave absorbing material are mounted about the substrate to absorb spurious microwave energy over a major portion of the length of each ground-signal-ground trace pattern. In

accordance with this type of construction, a high frequency impedance (e.g., 50 ohms) can be presented at the probe tips to the device under test. Thus broadband signals of eighteen gigahertz or less can travel with little loss across the coplanar transmission lines formed by each ground-signal-ground trace pattern.

The probing system of Lockwood et al., however, is insufficient to effectively probe non-planar surfaces. Such surfaces might result, for example, if the pads of the DUT differ in height, if a loose metallic particle of minute dimension adheres electrostatically to the surface of one of the pads of the DUT so as to form a non-planar surface irregularity, or when the plane of the DUT is inadvertently tilted slightly with respect to the plane of the coplanar tips of the probing assembly. Further, proper alignment between the needles and the DUT requires careful placement of each needle, a time consuming process.

The alignment limitation between the needles was addressed by Godshalk, U.S. Patent No. 5,506,515. Godshalk discloses a ground-signal-ground finger arrangement attached to a coaxial cable, as in Lockwood. The fingers, however, are originally formed in one piece, joined together by a carrier tab at the contact ends. Once the fingers are attached to the coaxial cable, the carrier tab is severed and the contact fingers appropriately shaped for contact with the DUT. Godshalk discloses that the relative position of each finger is held in alignment first by the carrying tab, and then by the coaxial cable. Unfortunately, Godshalk's design is limited in that the close placement of a coaxial cable to the finely spaced geometry of the DUT places a limit on the number of coaxial cables, and hence contact fingers, that may be used effectively in the probe. Further, a probe having multiple adjacent coaxial cables, each of which has different flexibilities, may lead to insufficient contact with some of the nodes on the DUT.

Another class of probes that provide clean power to circuits at low impedance are generally referred to as power bypass probes. Another configuration that has been developed to counteract the inductance at the tips of a probe assembly is a power bypass quadrant. The power bypass quadrant minimizes such inductance by providing integrated capacitors or resistor-capacitor networks within the probe.

Strid, U.S. Patent. No. 4,764,723, discloses a power bypass quadrant probe that utilizes an array of ceramic fingers coated with a thin gold or polyimide film to make contact with the DUT. The test signals are routed through a power bypass structure consisting of an RC network. Because of the small geometries near the DUT, the capacitors are located far away from the probe tip, which potentially decreases performance. In addition, the ceramic contact fingers tend to break during probing, particularly when the probe overshoots the contact pads. Further, probing pads that are not coplanar is exceedingly difficult because the ceramic contacting fingers lack flexibility.

Boll et al., U.S. Patent. No. 5,373,231 disclose a probe that includes an array of blades to contact the pads of a DUT. The array of blades extend from a transmission line network traced on a circuit board. An RC network is provided on the circuit board to provide the requisite power bypass, and in some instances, flexible capacitors are located close to, or between the contact blades. Because of the limited geometries near the DUT, the capacitance of the capacitors interconnected between the blades are small, and alone are insufficient to adequately eliminate circuit inductance. Accordingly, a second bank of capacitors with larger values are located away from the probe tip where space is available. Probes utilizing flexible capacitors between the closely spaced blades of the probe have proven to be of limited mechanical durability.

What is desired, therefore, is a configurable, multi-contact probe for high frequency testing of integrated circuits or other microelectronic devices that reduces the inductance at the probe tip to levels acceptable for measurement over a wide range of frequencies. The probe should be sufficiently durable and flexible to reliably and repeatedly probe substantially non-planar devices over time. It is further desired that the probe be easily aligned with the contact points on the device to be tested and that the probe be capable of simultaneously probing a number of such contact points.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a top view of an exemplary embodiment of the probe head of the present invention.

FIG. 2 shows a bottom view, at an enlarged scale, of the probe head of FIG. 1.

FIG. 3 shows an enlarged view of the probe tips attached to a common carrying tab of the probe head of FIG.1.

FIG. 4A shows a schematic of the electrical trace patterns of the top face of the exemplary probe head of FIG 1 including a power bypass feature.

FIG. 4B shows a schematic of the electrical trace patterns of the bottom face of the exemplary probe head of FIG 1 including a power bypass feature.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIGS. 1 and 2 illustrate an exemplary wafer probe 10. The wafer probe 10 includes an integrated tip assembly 12 mounted to a circuit board 14. The integrated tip assembly 12 comprises a plurality of contact fingers 16 extending from the circuit board 14 in a radially inward direction so as to match the compact geometry of the device

under test (not shown). The distal end portion 17 of each contact finger is shaped to provide a reliable electrical connection with an associated pad on a device under test. The circuit board 14 has electrical traces that route signals from the contact fingers 16 through a resistor-capacitor (RC) network 20 to pin connectors 22. Measurement cables (not shown) may be electrically connected to the pin connectors.

The wafer probe 10 is designed to be mounted on a support through a three hole mounting frame 24 of a wafer probe station so as to be in a suitable position for probing a device under test, such as an individual component on a semiconductor wafer. In this type of application, the wafer is typically supported under vacuum pressure on the upper surface of a chuck that is part of the same probing station. Ordinarily an X-Y-Z positioning mechanism is provided, such as a micrometer knob assembly, to effect movement between the supporting member and the chuck so that the tip assembly of the wafer probe can be brought into pressing engagement with the contact pads of the device under test.

Referring to FIG. 3, the integrated tip assembly 12 is fashioned as a unitary device with the individual contact fingers 16 connected by a common carrying tab 26 at the probing end. Each individual contact finger 16 is positioned so that, after the integrated tip assembly 12 is attached the circuit board 14, the common carrying tab 26 may be severed, leaving the distal end 18 of each contact finger in the appropriate position for probing the contact pads of the device under test.

The spacing of the contact fingers 16 at their respective distal ends 18 is selected to match the geometry of the DUT pads. Use of an integrated tip assembly 12 advantageously serves to maintain this proper spacing while the contact fingers 16 are attached to their respective connections to the circuit board 14. Typically, contact fingers

or needles are attached to a circuit board by being held flush to their respective traces and soldered into the appropriate position and pitch. During this process, lateral forces tend to displace the distal ends of the contact fingers, making it difficult to maintain the proper spatial relationship between the contact fingers to match that of the pads of the DUT. Use of a carrying tab 26, however, maintains the proper transverse spacing of the distal ends 18 of the contact fingers 16 by counteracting any lateral forces encountered in the attachment process.

In addition, the probe 16 described herein achieves an improved spatial transformation between the compact geometry of the microelectronic device being probed and the dispersed geometry of the testing equipment and, if provided, any power bypass circuitry. This improved spatial characteristic stands in contrast to earlier design, in which signals were routed through a coaxial cable. A coaxial cable, having simply an inner and an outer conductor, limits the number of attached contact fingers to three, arranged in a ground-signal-ground arrangement. Accordingly, any common carrying tab used to hold the contact fingers in position during their attachment to a coaxial cable also is limited to a maximum of three contact fingers.

Oftentimes, however, the DUT has more than three pads to be tested. In such a case, configuring the probe requires the use of multiple coaxial cables arranged in an adjacent relationship to each other, usually an awkward process given the limited space available near the probe tips. Use of multiple coaxial cables is also problematical in that different cables have differing flexibility, making it difficult to line up all the cables in a single plane and leading to uneven probe forces when the contact fingers are pressed to their respective pads. Moreover, the used of multiple coaxial cables and multiple carrying tabs necessitates the careful and time consuming adjustment of the relative

position between the sets of contact fingers to the geometry of the pads of the DUT. In another design, the use of multiple coaxial cables and a single carrying tab necessitates the careful and time consuming adjustment of the relative position of the coaxial cables.

Use of a circuit board 14, however, addresses each of these drawbacks. Because the circuit board 14 can include separate traces for each of the contact pads of the DUT to which the probe will be engaged during testing, the common carrying tab 26 depicted in FIG. 3 may include four or more contact fingers 16, maintaining all of their respective distal ends in their proper position until each finger 16 is rigidly attached to the circuit board 14. The circuit board 14 provides a controlled and uniform flexure, assuring not only a uniform amount of overtravel when the fingers 16 make contact with the pads of the DUT, but also a mechanism by which the stress in the contact fingers 16 may be relieved by the uniform flexibility of the circuit board 14. This flexibility may even be controlled by the selection of material for the circuit board 14.

FIG. 3 shows an example of an integrated tip assembly having the common carrying tab 26 still attached. The fingers 16 are generally of rectangular cross section and are preferably composed of the same material, where the material is selected from those metals that are capable of high resiliency to enable the fingers to probe a device having associated contact surfaces that are in non-planar arrangement. In the preferred embodiment, the fingers are formed of beryllium-copper (BeCu) which has been gold plated in order to reduce resistive losses. This material is particularly suited for the probing of contact pads that are formed of gold, since BeCu is substantially harder than gold. This, in turn, results in minimal wear and a long, maintenance free period of operation of the probe.

If the pads of the device are formed of aluminum instead of gold, it is preferable

to use a harder material for the fingers 16, such as tungsten. Here again, the finger material selected is substantially harder than the contact pad material in order to ensure minimal wearing of the fingers 16. If tungsten fingers are used, it is preferable that they also be gold plated to reduce resistive losses. Use of materials such as BeCu and tungsten allows repeated use of the probe while avoiding the fragility encountered through the use of the ceramic contact fingers described earlier. It should also be noted that other potential materials may be used, in addition to BeCu or tungsten. In addition, a number of other potential techniques exist to connect the contact fingers with the circuit board besides soldering, including epoxy and the like.

The contact fingers 16 are fabricated as a single, integrated unit attached to a common carrying tab 26 at the distal (tip) ends 18. The distal end 18 has a shape that provides a geometrical fanning of the contacts from the very small pitch (center-to center contact spacing) at the distal ends 18 up to the larger geometry of the traces 40 on the circuit board 14.

In accordance with one preferred assembly method, to prepare for connection of the respective contact fingers to the circuit board, solder paste is evenly applied to the exposed traces on the circuit board. The fingers are then held just above their corresponding traces, then lowered until they press against the solder paste in an appropriate position. When the solder is melted, preferably by heating elements arranged above and below the connection region a solder fillet is desirably formed between each finger and its corresponding circuit board trace.

Preferably, while heating the solder, the fingers are held at a slight downward incline relative to the distal ends so that during cooling, each finger assumes a planar relationship with the circuit board 14. During this connection process, it will be noted

that the proper transverse spacing is maintained between the respective fingers by the common carrier tab since any forces that would tend to laterally displace the fingers are negated by the common carrier tab 26 that holds the contact fingers at their respective distal ends. 18

After the fingers 16 are attached to the circuit board 14, the common carrier tab 26 is severed as it is no longer needed because proper finger alignment is maintained by the circuit board 14. The fingers 16 are preferably shaped using grinding and lapping processes to create a flat contact area whose leading edge is visible when viewed from directly above.

Referring to FIG. 1 and FIGS. 4A and 4B, the circuit board electrical traces 40 provide continued geometrical fanning to even larger dimensions, ultimately leading to one or more connectors such as the set of pins shown in FIG. 1, typically of a much larger physical scale. The circuit board 14 may have a ground plane (not shown) providing reduced ground inductance and controlled impedance of the signal traces 40 - usually 50 ohms for use with standard test equipment. Use of a circuit board 14 also allows for the optional use of very small dimension Surface Mount Technology (SMT) components that can be placed at an intermediate level of geometric scaling.

As shown in FIG. 1 and FIG. 2, the structure is compatible with a power bypass architecture that can be mounted on the surface of the circuit board 14. In the preferred embodiment both surfaces of the circuit board are used to provide the power bypass feature in order to utilize the additional space.

To illustrate how such a power bypass structure may be incorporated, FIGS. 1 and 2 depict a power bypass architecture spread over both surfaces of the circuit board 14. It should be noted, however, that it is entirely feasible to provide a complete power

bypass structure using only one surface of the circuit board if so desired. In this illustration, the four contact fingers 50, 52, 54, 56 are arranged in an adjacent relationship, alternating between power and ground contacts. On the bottom surface of the circuit board, depicted FIG. 2, a high frequency metal-insulator-metal (MIM) capacitor is attached between the adjacent power and ground transmission lines formed by respected pairs of contact fingers.

While the MIM capacitor has very low inductive parasitics and a very high self-resonant frequency it does not have very much capacitance. This limits its ability to provide power bypass at lower frequencies. Accordingly, a relatively larger sized and valued SMT capacitor, though still of very small physically dimension, is placed further up the board where there is sufficient space. A small value SMT resistor is used in series with this capacitor to “de-Q” or spoil the parallel resonance that can occur between the MIM capacitor and the inductance of the line length running to the SMT capacitor.

Referring specifically to FIGS. 4A and 4B, the circuit board is designed to allow customization of the function, i.e. ground, signal, power, etc., of each electrical contact of the probe. Initially, each of the fingers is connected to a via to the ground plane, to an SMT component and eventually to the connector. Programming a ground contact requires simply leaving the connection to the ground intact, while for all other functions this small circuit board trace is cut away, with a sharp blade or a laser for instance. When programming a bypassed power line the connection to the SMT component is left intact while the short

circuit trace to the ground is cut.

Referring again to FIG. 1, the probe design preferably includes an inclined circuit board 14 relative to the device under test. A major portion of the fingers 16 are likewise preferably aligned with the plane of the circuit board 14 with the distal ends 18 being shaped for appropriate probing of the device under test. This inclined design permits the circuit board 14 to be spaced apart from the device under test during testing, while simuitaneously permitting the fingers 16 to be short, which minimizes inductance to increase performance. Otherwise, the fingers would need to be mounted in an inclined manner with respect to the circuit board, which in many cases, would require longer fingers for effective probing.